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**PHYSIOLOGICAL STRESS FROM CHEMICAL
DEFENSE CLOTHING AND EQUIPMENT**

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The voluntary, fully informed consent of the subjects used in this research was obtained as required by AFR 169-3.

The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

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PHYSIOLOGICAL STRESS FROM CHEMICAL DEFENSE CLOTHING AND EQUIPMENT

Groundcrew Heat Stress Caused by Wearing Chemical Defense Clothing

Current U.S. Air Force (USAF) guidance on control of heat stress in chemical defense operations is incorporated into work-rest tables in AFR 355-8, Mission Oriented Protective Postures. The regulation is being revised to make it more useful in the field, but questions remain regarding the efficacy of the prescribed work-rest cycles for control of hyperthermia. Experiments conducted under USAF sponsorship indicated large individual differences in recovery time.

Experience at the Armstrong Laboratory indicated that even thermally acceptable work-rest cycles produced cumulative fatigue which would curtail the duty day. A study was performed to test for possible effects of consecutive daily exposure to work in the chemical defense ensemble (CDE). Subjects wore the current groundcrew CDE and pedaled a cycle ergometer at 38 W in a room at 29 °C. They worked until rectal temperature (Tre) reached 38.3 °C, then rested in a room at 21 °C until Tre declined to 38.0 °C, repeating work and rest for 4 h or to volitional fatigue. Results showed large intra- and inter-subject variability but no significant effect related to the 4-day repetition.

A related study was designed to evaluate heat stress and fatigue when work-rest cycles are followed for an entire duty day. Subjects wore the current USAF groundcrew CDE. Initial experiments are being conducted at ambient temperatures of 21 and 27 °C (70 and 80 °F) at low and moderate work rates. Work and rest intervals were controlled to produce cyclic changes in Tre with peaks at either 38.5 or 39.0 °C and end-rest values of 38.0 or 38.2 °C, respectively. No cumulative effects were found.

Validation of the Heat-Humidity Index for Work in CDE

A study was conducted using a matrix of experiments designed to validate the Texas Model of Human Thermoregulation with respect to the net heat stress on subjects working in CDE in various combinations of dry bulb and wet bulb temperature (Tdb = 22-40 °C, Twb = 18-30 °C). The model provided satisfactory prediction of human tolerance limits for severe heat stress (tolerance time ≤ 60 min). Under milder conditions the model appears to overestimate the evaporation of sweat through the CDE, indicating the need for improved understanding of vapor transport within clothing

systems. The experiments validated the use of "Discomfort Index" as an index of environmental heat load with the current CDE, where $DI = (T_{db} + T_{wb})/2$.

Evaluation of CDE Made with Various Materials

Tests were conducted to compare the heat stress caused in vivo by several different CDEs made of several materials. Subjects walked on a treadmill at 3 mph on a 5% grade to produce a metabolic rate of about 420 W. Environmental conditions were $T_{db} = 40^\circ\text{C}$ and $T_{wb} = 24^\circ\text{C}$ (20% relative humidity (RH)). Measurements included heart rate, T_{re} , skin temperatures, and heat flux. Early indications are that garments made with von Blücher Saratoga technology allow significant evaporative cooling. Suits which fit in that category include the von Blücher PJ-7 (without Goretex), the new USAF flight suit (CWU-66/P), and the US Marines "light-fighter" two-piece suit. Skin temperatures remain lower and tolerance times are much longer in those suits than in the current USAF groundcrew CDE or PJ-7 with a Goretex outer garment.

Groundcrew Cooling Devices

The USAF deployed individual groundcrew cooling equipment in the Middle East including contractor-fabricated Air Distribution Units (ADUs) and air vests. The ADU takes chilled air from an avionics cooling cart, passes it through large CD filter canisters and then routes the air to a manifold with ten ports, each delivering filtered air at 566 L/min (20 cfm) and $15\text{--}20^\circ\text{C}$ ($59\text{--}68^\circ\text{F}$). Groundcrew members wear an air distribution vest and tether themselves to the ports during rest breaks; the air is piped to both vest and the face mask. Laboratory experiments show that such a system provides effective cooling and improved comfort. A further advantage is the potential protection offered by positive pressure provided to the face mask and the suit microclimate. The equipment was never used, as the conflict did not extend into hot weather. Meanwhile, it became apparent that the avionics cooling carts to be used with the system were not readily available as expected; in response, in-house personnel developed a Pressurized Air Distribution Unit which would allow use of tent air-conditioners as a cooling source for the ADUs.

Continued progress has been made toward development of a lightweight belt pack to improve groundcrew comfort by ventilating the CDE with filtered air at ambient temperature. The prototype unit weighs 4 kg and delivers 4.5 L/s (10 cfm) to the torso and 1 L/s (2 cfm) to the face mask. Seven subjects performed work-rest experiments while wearing CDE in a chamber at $T_{db} = 32^\circ\text{C}$, RH=40 %. They walked on a treadmill at 450 W for 40 min and then rested for 20 min, repeating the cycle four times if possible. Test conditions included control (NC, no cooling), intermittent cooling (IC, chilled air during rest breaks), and continuous cooling (CC, ambient air during work

and chilled air during rest). Both IC and CC produced significant improvements over NC. In addition, CC provided better results than IC with respect to skin temperature, evaporation of sweat, and thermal comfort. Further work is planned to reduce belt pack weight, increase air flow, and optimize work-rest cycles.

Aircrew Guidelines

Experience with a more comprehensive index of heat stress for a wide range of aviation scenarios; the Aircrew Thermal Stress Index is being circulated as draft NATO STANAG 3945, Guidelines for Thermal Limitations Imposed by Aircrew NBC Assemblies.

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